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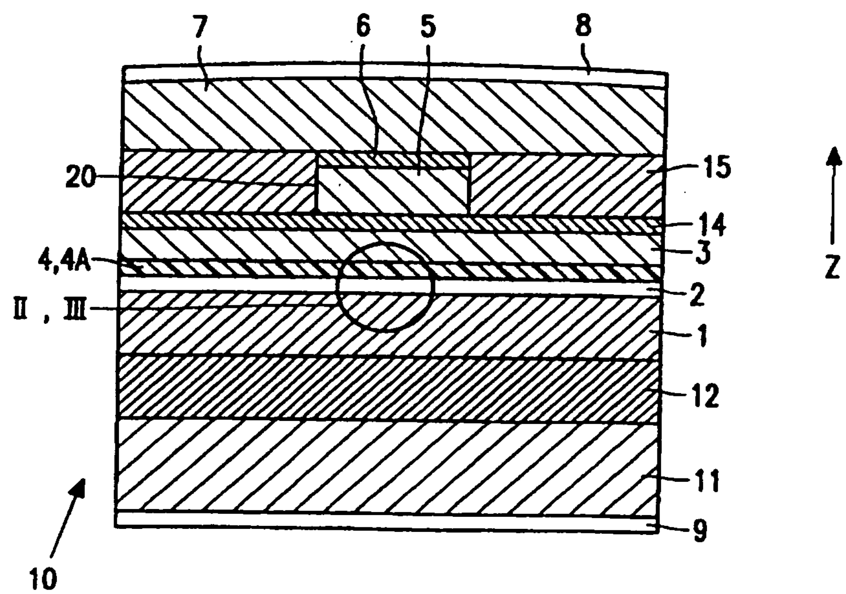
(54) Title: RADIATION-EMITTING SEMICONDUCTOR DIODE, AND METHOD OF MANUFACTURING SAME

(57) Abstract



The invention relates to a radiation-emitting semiconductor diode in the InGaP/InAlGaP material system having a barrier (4A) for charge carriers situated between the active layer (2) and one of the cladding layers (1, 3). Such a diode has an emission wavelength between 0.6 and 0.7 μm and is particularly suitable, when constructed as a diode laser, for serving as a radiation source in, for example, a system for reading and/or writing of optical discs, also because of an increased efficiency. A disadvantage of the known diode is that it is still insufficiently capable of providing a high optical power, and that it cannot be manufactured with a high yield and a satisfactory reproducibility. In a diode according to the invention, the barrier (4A) comprises only a single barrier layer (4) of AlP. Such a diode is found to have a surprisingly high efficiency as well as a particularly long useful life. The efficiency of the diode is approximately 30 % higher than that of a comparable diode without a barrier layer (4). The life of a diode according to the invention is very long, for example, 4,000 hours. Since the problem of controlling the composition of the barrier layer (4) is nonexistent in providing the AlP, the diode according to the invention can be manufactured with a good reproducibility and high yield. The AlP barrier layer (4) preferably has a thickness smaller than 5 nm, for example 2.5 nm. It is highly suprising that such a very small thickness of the barrier layer (4) is still accompanied by an excellent effectiveness as a barrier (4A).

Radiation-emitting semiconductor diode, and method of manufacturing same.

The invention relates to a radiation-emitting semiconductor diode, in particular a semiconductor diode laser which will be called mostly diode hereinafter for short, with a semiconductor body comprising a substrate of a first conductivity type and preferably made of GaAs and with a semiconductor layer structure situated thereon and comprising at least a first cladding layer of the first conductivity type and made of InAlGaP or InAlP, a second cladding layer of a second conductivity type opposed to the first and also made of InAlGaP or InAlP, and between the first and second cladding layers an active layer of InGaP or InAlGaP and a pn junction which, given a sufficient current strength in the forward direction, is capable of generating electromagnetic radiation through recombination of charge carriers in a strip-shaped active region forming part of the active layer, the first and the second cladding layer being connected to connection conductors, while a barrier for the charge carriers is present between the active layer and the first or second cladding layer, which barrier has a greater bandgap than the first or second cladding layer. The invention also relates to a method of manufacturing such a diode.

Such a diode emits between 0.6 and 0.7 μm and is suitable as a laser inter alia for use as a radiation source in a system for optical discs which can be read and/or written, in a laser printer, or a bar code reader.

Such a diode is known from USP 5,274,656 published 28th December 1993. The diode known from this document comprises a barrier for charge carriers formed by an InAlGaP or InAlP layer situated between the active layer and a cladding layer. In addition, according to the cited document, the barrier may comprise a MQB (= Multi Quantum Barrier) layer structure with alternating quantum well layers and barrier layers. A possible thickness for the charge carrier barrier is indicated as lying between 5 and 10 nm. The barrier is such that the (radiation) beam of the diode reaches from the active layer through the barrier into the cladding layer. The combination of such a barrier having a great bandgap with a cladding layer having a small bandgap has the following purposes: on the one hand a good confinement of the charge carriers in the active layer owing to the great

small distance from the barrier to the active layer. It was indeed found experimentally that a diode according to the invention has a surprisingly long life. The excellent effectivity of a barrier having such a small thickness, for example a thickness of approximately 2.5 nm, is also very surprising because it is generally assumed that a barrier must have a thickness greater than 10 nm in the case of electrons and greater than 5 nm in the case of holes for preventing the relevant charge carriers from tunneling through the barrier, cf. for example EPA 0,540,799 published 12-5-1993, especially p. 7, ll. 1-16.

Although a barrier may be present on both sides of the active layer, which barriers will then each comprise only a single barrier layer according to the invention, a diode according to the invention preferably comprises a barrier of a single barrier layer only between the active layer and that cladding layer which is of the p-conductivity type. It was found that an additional barrier between the active layer and the n-type cladding layer substantially does not contribute to an increase in the efficiency. To minimize the tension in the diode, and thus to increase its life, the latter barrier is preferably omitted.

In a very favorable modification, the barrier layer is present within a distance from the active layer which is equal to the diffusion length of the charge carrier. The barrier will be effective when this is the case. This means, for example, that a barrier layer present between the active layer and the p-type cladding layer should be at a distance of less than 40 nm from the active layer. Preferably, the barrier layer lies at the interface between the active layer and a cladding layer. It is also possible, however, for the barrier layer to lie (just) within a cladding layer or separate confinement layer.

Preferably, the active layer of a diode according to the invention has a multi quantum well structure of alternating quantum well layers of GaInP or InAlGaP and further barrier layers of InAlGaP. The multiquantum well structure may also be surrounded by further barrier layers of InAlGaP, but is preferably surrounded by separate confinement layers of InAlGaP. In that case the starting current of a diode according to the invention is a minimum, so that it is highly suitable for applications where a high output power of the diode is desired. For the same reason the quantum well layers are preferably given a mechanical stress caused by a lattice constant different from that of the substrate. A tensional stress in the quantum well layers makes the emission wavelength of the diode lower. Not only a high power, but also a wavelength which is as small as possible is necessary for the application mentioned above of a radiation source in a system of optical discs which can be read and/or written. A small wavelength allows of a system with a high information density. Particularly favorable results are obtained with a diode whose active layer comprises two

Fig. 1 shows a first and a second embodiment of a diode according to the invention, here in the form of a diode laser, in a diagrammatic cross-section perpendicular to the longitudinal direction of the resonance cavity. The diode comprises a semiconductor body 10 with a substrate 11 of a first, here the n-conductivity type comprising monocrystalline GaAs in this example and provided with a connection conductor 9. A semiconductor layer structure is provided thereon, in this example comprising a buffer layer 12 of n-AlGaAs, a first cladding layer 1 of n-InAlGaP, an active layer 2 of InGaP and InAlGaP, a second cladding layer 3 of p-InAlGaP, a third cladding layer 5 also of p-InAlGaP, an intermediate layer 14 of InGaP, a transition layer 6 of InGaP, and a contact layer 7 of p-GaAs. A pn junction is present between the first cladding layer 1 and the second cladding layer 3. The intermediate layer 14 here serves inter alia as an etching stopper layer during the formation of the strip-shaped mesa 20 which comprises the third cladding layer 5 and the transition layer 6. On either side of the mesa 20 and between the intermediate layer 14 and the contact layer 7 there is a current-blocking layer 15 of n-GaAs here. A strip-shaped active region arises below the mesa 20 in the active layer 2 during operation. Two end faces of the semiconductor body 10 bounding the strip-shaped active region and acting as mirror surfaces for a resonance cavity of the laser-type diode here lie parallel to the plane of drawing. The diode in this example is of the index-guided and BR (= Buried Ridge) type. The electrical connection of the pn junction situated between the first and the second cladding layer 1, 3 is effected through connection conductors 8, 9 on the contact layer 7 and the substrate 1, respectively.

Figs. 2 and 3 diagrammatically show the semiconductor layer structure and the gradient of the conduction band in the thickness direction (z) in the surroundings of the active layer 2 of the diode of Fig. 1. The active layer 2 here comprises a multi quantum well structure with two quantum well layers 2A which are separated from one another by a further barrier layer 2B and are surrounded by two separate confinement layers 2C. Between the active layer 2 and the first or second cladding layer 1, 3, here the second cladding layer 3, there is a barrier 4A (see Figs. 1 to 3) for charge carriers which has a greater bandgap than the relevant cladding layer 1, 3, so here than the second cladding layer 3.

According to the invention, the barrier 4A is formed by only a single barrier layer 4 made of AlP. In contrast to a MQB barrier, which only functions satisfactorily when the charge carriers from the active layer 2 are coherent, which is found to be not the case in practice, a barrier 4A comprising a single barrier layer 4 does operate excellently, provided it is made from AlP. Firstly, such a barrier layer 4 results in a major

Layer	Semiconductor	Type	Conc. (at/cm³)	d (μm)	Δa/a (%)
11	GaAs	N	$2x10^{18}$	350	0
12	$Al_{0.20}Ga_{0.80}As$	N	$2x10^{18}$	0.1	0
1	$In_{0.50}Al_{0.35}Ga_{0.15}P$	N	$5x10^{17}$	1.4	0
2A	$In_{0.62}Ga_{0.38}P$	-	-	0.008	+1.0
2B	$In_{0.42}Al_{0.23}Ga_{0.35}P$	-	-	0.016	-0.5
2C	$In_{0.50}Al_{0.20}Ga_{0.30}P$	-	-	0.030	0
4	AlP	-	-	0.0025	-3.5
3	$In_{0.50}Al_{0.35}Ga_{0.15}P$	P	$3x10^{17}$	0.3	0
5	$In_{0.50}Al_{0.35}Ga_{0.15}P$	P	$3x10^{17}$	1.1	0
6	$In_{0.49}Ga_{0.51}P$	P	$1x10^{18}$	0.01	0
7	GaAs	P	$2x10^{18}$	0.8	0
14	$In_{0.49}Ga_{0.51}P$	P	$1x10^{18}$	0.05	0
15	GaAs	N	$1x10^{18}$	0.8	0

The width of the mesa 20 is 5 μm. The length and width of the semiconductor body 10 and the length of the mesa 20 are approximately 500 μm. The conductive layers 8, 9 are of usual thickness and composition. The emission wavelength of the diode of this embodiment is 635 nm. The manufacture of the diode by a method according to the invention will be described below.

Figs. 4 to 6 diagrammatically show the diode of Fig. 1 in consecutive stages of its manufacture by a method according to the invention. In a first growing process (see Fig. 4), the layers 12, 1, 2, 4, 3, 14, 5 and 6 are provided in that order on a substrate 11. MOVPE (= Metal Organic Vapor Phase Epitaxy) is used for this. The materials, compositions, and thicknesses according to the invention are chosen for these layers, see the Table above. More in particular, a barrier layer 4 of AlP is provided according to the

Claims:

1. A radiation-emitting semiconductor diode with a semiconductor body (10) comprising a substrate (11) of a first conductivity type and preferably made of GaAs and with a semiconductor layer structure situated thereon and comprising at least a first cladding layer (1) of the first conductivity type and made of InAlGaP or InAlP, a second cladding layer (3) of a second conductivity type opposed to the first and also made of InAlGaP or InAlP, and between the first and second cladding layers (1, 3) an active layer (2) of InAlGaP or InGaP and a pn junction which, given a sufficient current strength in the forward direction, is capable of generating electromagnetic radiation through recombination of charge carriers in a strip-shaped active region forming part of the active layer (2), the first cladding layer (1) and the second cladding layer (3) being connected to connection conductors (8, 9), while a barrier (4A) for the charge carriers is present between the active layer (2) and the first or second cladding layer (1, 3), which barrier has a greater bandgap than the first or second cladding layer (1, 3), characterized in that the barrier (4A) is formed by only a single barrier layer (4) comprising AlP.

2. A radiation-emitting semiconductor diode as claimed in Claim 1, characterized in that the barrier layer (4) has a thickness smaller than 5 nm.

3. A radiation-emitting semiconductor diode as claimed in Claim 1 or 2, characterized in that the barrier layer (4) has a thickness which is approximately equal to 2.5 nm.

4. A radiation-emitting semiconductor diode as claimed in Claim 1, 2 or 3, characterized in that a barrier (4A) in the form of a single barrier layer (4) is present exclusively between the active layer 2 and that cladding layer (3) which is of the p-conductivity type.

5. A radiation-emitting semiconductor diode as claimed in any one of the preceding Claims, characterized in that the barrier layer (4) is present within a distance from the active layer (2) equal to the diffusion length of the charge carrier.

6. A radiation-emitting semiconductor diode as claimed in any one of the preceding Claims, characterized in that the active layer (2) has a multi quantum well structure (2A, 2B) of alternating quantum well layers (2A) of InGaP or InAlGaP and further

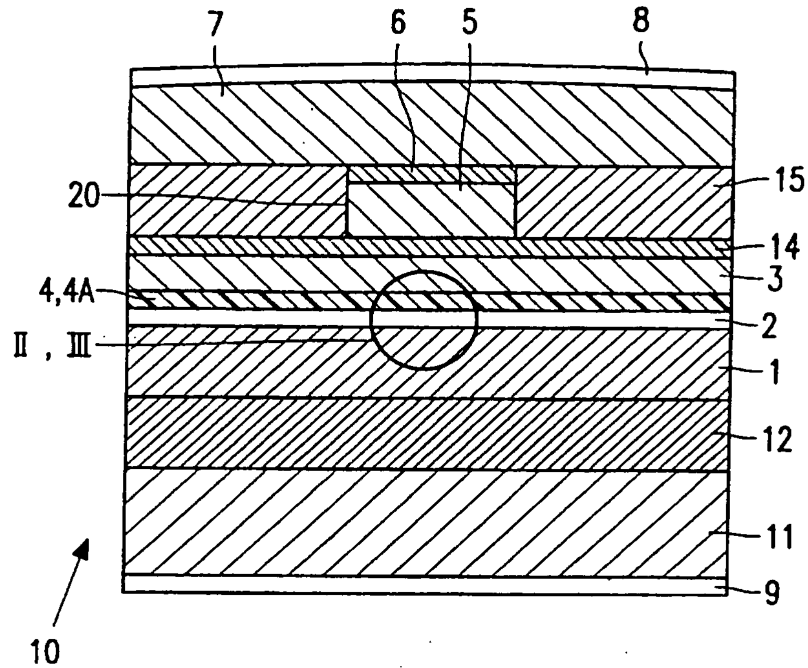


FIG. 1

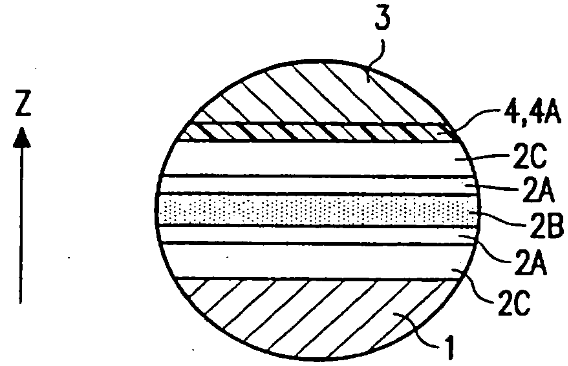


FIG. 2

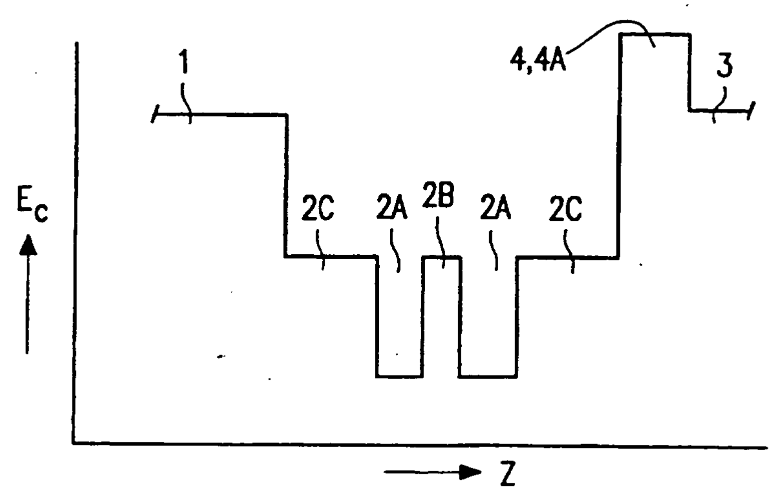
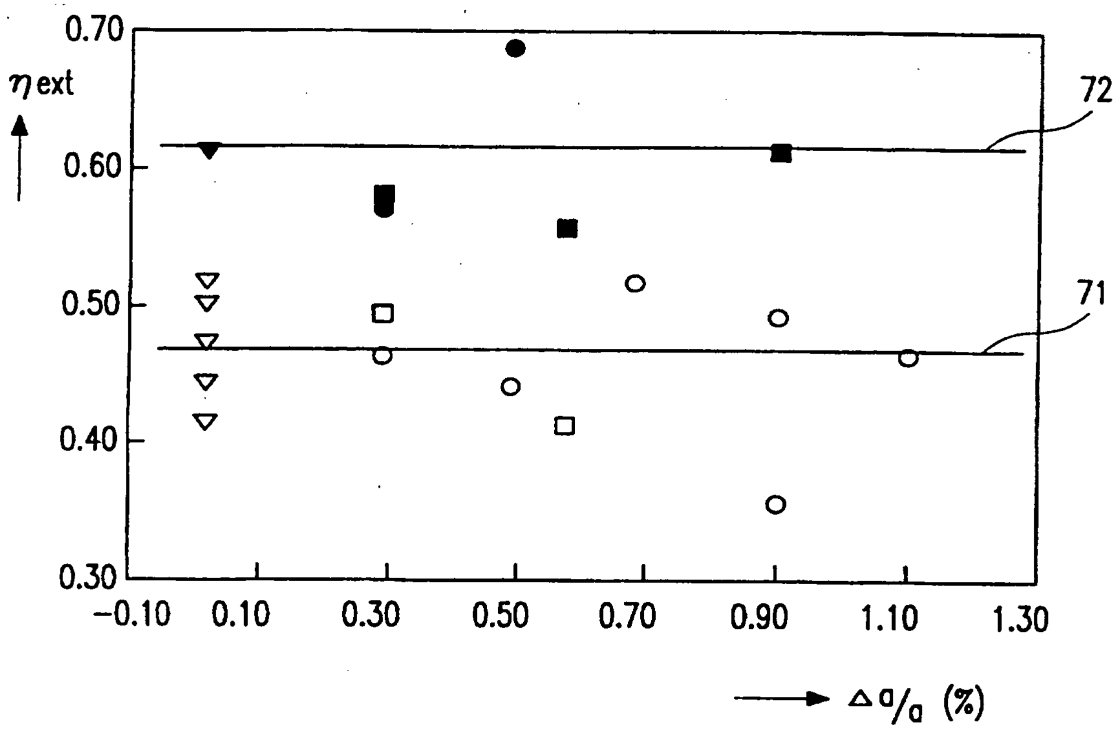


FIG. 3


0.70
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71
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0.50
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1.10
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Δa/a (%)

FIG. 7

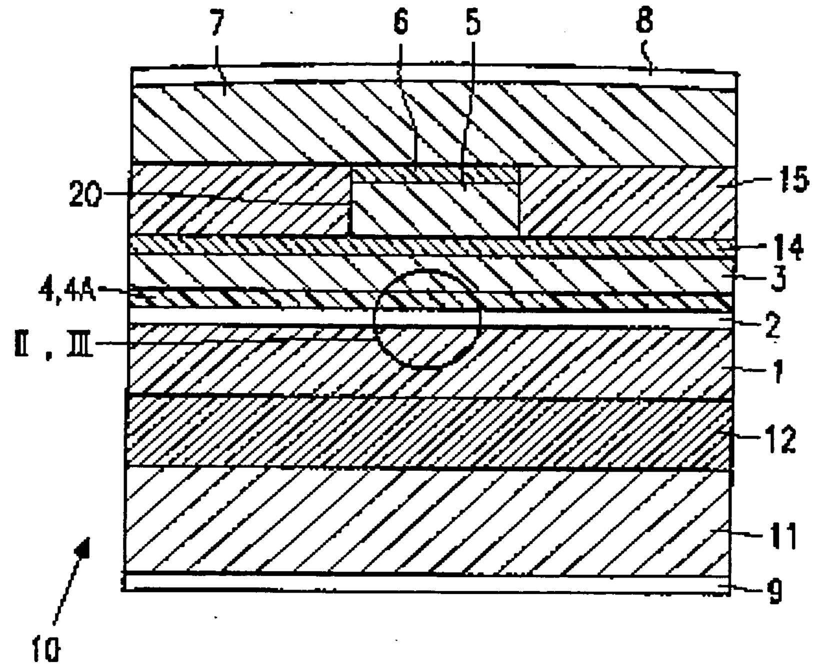


FIG. 1

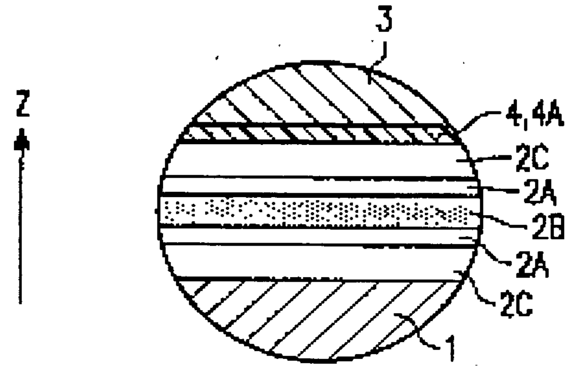


FIG. 2

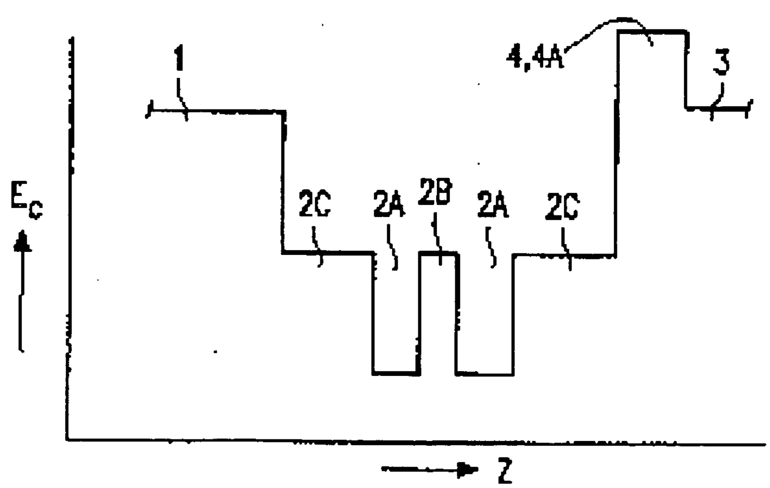
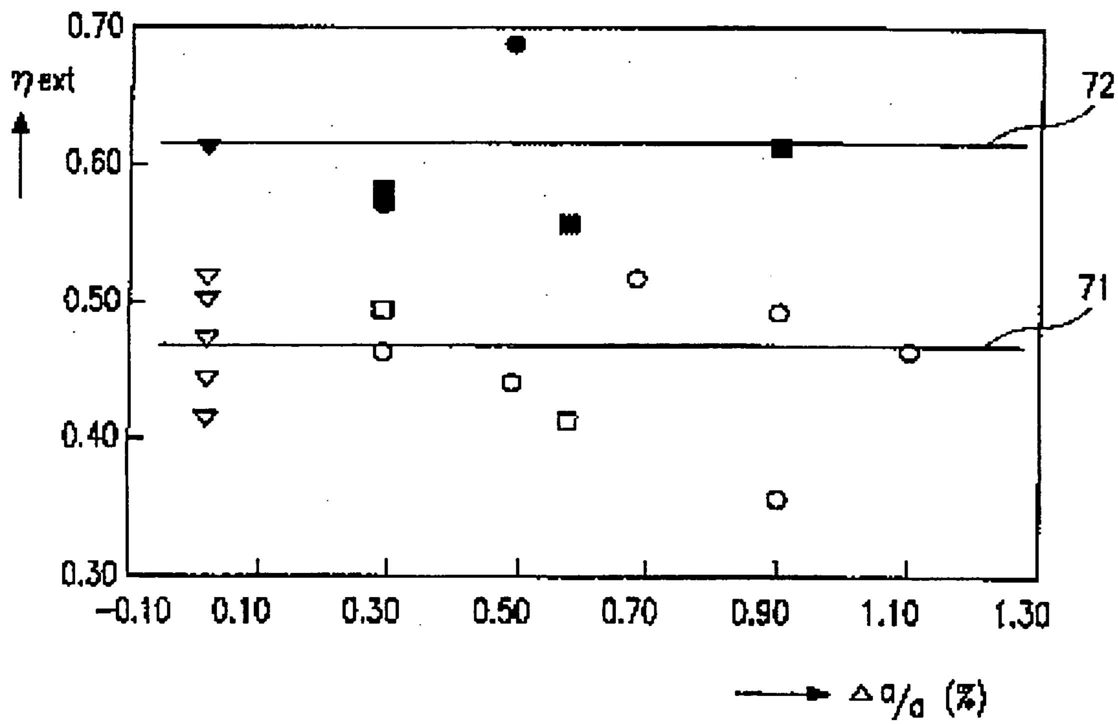


FIG. 3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0.30
η ext
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71
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0.10
0.30
0.50
0.70
0.90
1.10
1.30
Δa/a (%)

FIG. 7

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(81) Designated States: JP, European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

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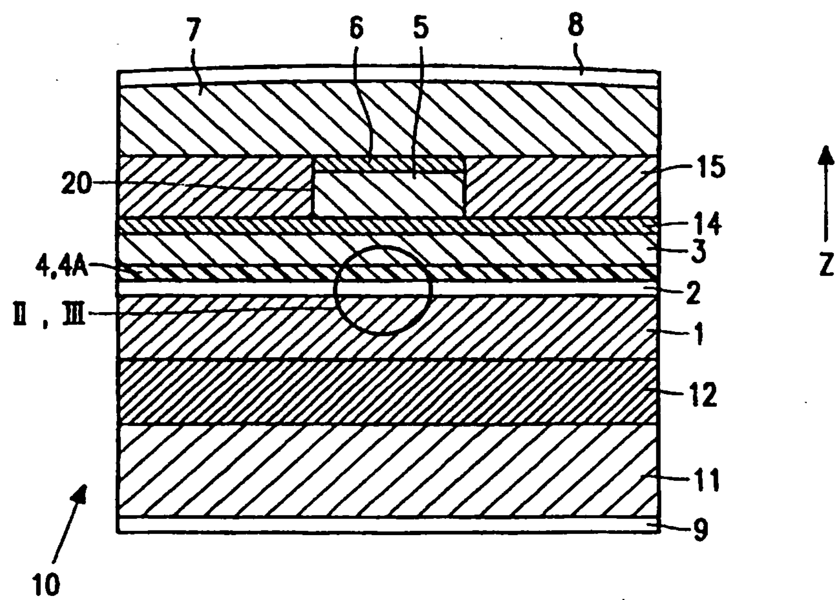

(57) Abstract

The invention relates to a radiation-emitting semiconductor diode in the InGaP/InAlGaP material system having a barrier (4A) for charge carriers situated between the active layer (2) and one of the cladding layers (1, 3). Such a diode has an emission wavelength between 0.6 and 0.7 μm and is particularly suitable, when constructed as a diode laser, for serving as a radiation source in, for example, a system for reading and/or writing of optical discs, also because of an increased efficiency. A disadvantage of the known diode is that it is still insufficiently capable of providing a high optical power, and that it cannot be manufactured with a high yield and a satisfactory reproducibility. In a diode according to the invention, the barrier (4A) comprises only a single barrier layer (4) of AlP. Such a diode is found to have a surprisingly high efficiency as well as a particularly long useful life. The efficiency of the diode is approximately 30 % higher than that of a comparable diode without a barrier layer (4). The life of a diode according to the invention is very long, for example, 4,000 hours. Since the problem of controlling the composition of the barrier layer (4) is nonexistent in providing the AlP, the diode according to the invention can be manufactured with a good reproducibility and high yield. The AlP barrier layer (4) preferably has a thickness smaller than 5 nm, for example 2.5 nm. It is highly suprising that such a very small thickness of the barrier layer (4) is still accompanied by an excellent effectiveness as a barrier (4A).

INTERNATIONAL SEARCH REPORT

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PCT/IB 97/00372

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H01S 3/19, H01L 33/00
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H01S, H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5509024 A (BOUR ET AL), 16 April 1996 (16.04.96), column 2, line 11 - column 4, line 20, figure 1, Claims 1,2,4,6-10,12,14-16 --	1-10
A	US 5274656 A (YOSHIDA), 28 December 1993 (28.12.93), column 2, line 10 - column 3, line 23, figure 5 --	1-10
A	US 4675708 A (ONABE), 23 June 1987 (23.06.87), column 2, line 16 - line 35, abstract --	1-10

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
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"P" document published prior to the international filing date but later than the priority date claimed
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"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 October 1997	22-10-1997
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Stig Edhborg Telephone No. +46 8 782 25 00

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		JP 61244086 A	30/10/86